Evaluation of Hemodynamic Changes Using Different Intra-Abdominal Pressures for Laparoscopic Cholecystectomy

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Abstract Biliary diseases known since ages constitute major portion of digestive tract disorders world over. Among these cholelithiasis being the fore runner causing general ill health, thereby requiring surgical intervention for total cure. The study was undertaken in an attempt to compare the hemodynamic changes in patient undergoing laparoscopic cholecystectomy using different intra-abdominal pressures created due to carbon dioxide insufflation. The patients were randomly allocated to one of the three groups in which different levels of intra-abdominal pressures (8–10 mmHg, 11–13 mmHg and 14 mmHg and above) were maintained. The base line parameters monitored were heart rate, non invasive blood pressure (systolic and mean) and end tidal carbon dioxide. All the parameters were monitored at various intervals i.e. Immediately during insufflation, 5 min, 10 min, 20 min, 30 min after CO₂ insufflation and after every 10 min if surgery exceeds 30 min, at

exsufflation, 10 min after CO₂ exsufflation. Patients were ventilated with Pedius Drager Ventilator keeping tidal volume 8–10 ml/kg and respiratory rate 12–14 breaths/min. During surgery patients were placed in reverse Trendelenburg position (head up) at 15°. The results obtained were evaluated statistically and analyzed. Baseline characteristics were found to be comparable. Hemodynamic variables were reported as mean and standard deviation. Statistical significance among groups was evaluated using Analysis of Variance and unpaired student *t* test (two tailed). Inter-group comparisons were made using Bonferroni test. A *p*-value of <0.05 was considered as statistically significant. In all the three groups the mean heart rate (baseline 84.08±12.50, 87.96±15.73 and 86.92±17.00 respectively) increased during CO₂ insufflation and the rise in heart rate continued till exsufflation after which it decreased and at 10 min after exsufflation the heart rates were comparable with the baseline. The inter-group comparison of mean heart rate between I & III was statistically significant at 10, 20, 30 min after CO₂ insufflation which continued at exsufflation and 10 min after CO₂ exsufflation [*p*<0.05]. The inter-group comparison between I & III showed statistically significant difference in systolic blood pressure at 10, 20, 30 min after CO₂ insufflation, at exsufflation and 10 min after exsufflation [*p*=0.0001] and mean arterial pressure at 5, 10, 20, 30 min after CO₂ insufflation, at exsufflation and 10 min after exsufflation [*p*=0.0001]. Comparison between Group I and Group III & between Group II and Group III showed highly significant statistical difference in EtCO₂ immediately after insufflation and the same trend was seen till the completion of surgery and even 10 min after exsufflation [*p*=0.001]. The conclusion drawn from the study was that laparoscopic cholecystectomy induces significant hemodynamic changes intraoperatively, the majority of pathophysiological changes are related to cardiovascular system and are caused by CO₂ insufflation. A high intra-abdominal pressure due to CO₂ insufflation is associated

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with more fluctuations in hemodynamic parameters and increased peritoneal absorption of CO₂ as compared to low intraabdominal pressure so low pressure pneumoperitoneum is feasible for laparoscopic cholecystectomy and minimizes the adverse hemodynamic effects of CO₂ insufflation.

Keywords Laparoscopic cholecystectomy · Insufflation · Hemodynamic · Intra-abdominal pressure

Introduction

The earliest reference to laparoscopy dates back to Biblical history. During ancient times, peritoneal cavity was the central focus, with umbilicus symbolizing the connection of life and liver representing the “cradle of the soul” [1].

The first endoscopic examinations of peritoneal cavity were accomplished early in the 20th century. In 1901, George Kelling, a German surgeon, used a cystoscope to examine the intra-abdominal viscera of a dog after insufflating the peritoneal cavity with air, and coined the term celioscopy. Jacobeus performed the first human celioscopy in Sweden in 1910 [2]. Liver biopsies were the first laparoscopic procedures attempted by general surgeons in 1982 [3]. In 1987, Mouret performed the first human laparoscopic cholecystectomy in France [4].

The use of laparoscopic technique in general surgery has gained increasing popularity in the last few decades. The small limited incisions are well accepted by the patients and there is the benefit of faster recovery. Health costs may be decreased by diminishing length of postoperative hospital stay and by reducing the need for postoperative analgesia [5]. The benefits reported after laparoscopic surgery explain its increasing success. However, intraoperative requirement of laparoscopic surgery produces significant physiological changes, some of which are unique to these procedures.

The physiological changes observed during laparoscopic surgery are a result of patient position, introduction of exogenous insufflation gas, CO₂, and increased intra-abdominal pressure due to pneumoperitoneum [6].

During laparoscopic cholecystectomy, patient is put in reverse Trendelenburg position to produce gravitational displacement of viscera away from the surgical site. It improves respiration and is considered favourable to respiration [5]. However, it results in decreased venous return, right atrial pressure, and pulmonary capillary wedge pressure resulting in the fall in mean arterial pressure and cardiac output [7].

Absorption of CO₂ from the peritoneal cavity is the potential mechanism for hypercarbia and rise in end-tidal CO₂ [8]. Severe hypercarbia exerts a negative inotropic effect on the heart and reduces left ventricular function [9].

The pneumoperitoneum produces increased intra-arterial pressure, CO₂ absorption, temperature variation, and neuro-hormonal stress response. The increased intra-abdominal

pressure influences all the major systems of the body, leading to significant hemodynamic and ventilatory changes [6]. Increased intra-abdominal pressure interferes with infra-diaphragmatic venous and arterial blood flow. It may also displace the diaphragm into the chest cavity, decreasing total lung capacity and functional residual capacity, adding to the acid–base disturbance. Cardiac output is decreased with increase in the ventricular stroke work and the heart rate. Pressure on the abdominal aorta also increases the pressure in the upper body. The ventilatory and circulatory changes can be appreciated within 5 min of the onset of insufflation of gas. Pressures of more than 15 mmHg are associated with significant pathophysiologic effects, but are reversible over a 2-hour period [10].

The extent of hemodynamic changes associated with the creation of pneumoperitoneum depends on the intra-abdominal pressure attained, volume of CO₂ absorbed, patient’s intravascular volume, ventilatory technique, and surgical conditions [11].

The frequent complications associated with creation of pneumoperitoneum include subcutaneous or mediastinal emphysema, pneumothorax, hypoxemia, hypotension, CO₂ embolism, cardiovascular collapse, and cardiac arrhythmias [11].

Several studies have concluded that low intra-abdominal pressure reduces the incidence of hemodynamic and ventilatory changes, leading to minimal and transient organ dysfunction and decreases the chances of physiological changes to transform into complications [12].

The study has been undertaken in an attempt to compare the hemodynamic changes in a patient undergoing laparoscopic cholecystectomy using different preset intra-abdominal pressures created due to carbon dioxide insufflation.

Materials and Methods

Patients with ASA I and II of either sex and age more than 18 up to 60 years scheduled to undergo elective laparoscopic cholecystectomy were included in the study. The patients were evaluated and a detailed general physical and systemic examination was conducted.

Patients with uncontrolled medical diseases such as hypertension, coronary artery diseases, diabetes mellitus, COPD, and asthma were excluded from the study. Patients with significant portal hypertension, uncorrectable coagulopathies, suspected gallbladder carcinoma, cirrhosis, and generalized peritonitis were also excluded from the study.

The patients were randomly allocated to one of the three groups in which different levels of intra-abdominal pressures were maintained during surgical intervention by CO₂ insufflation.

Table 1 Mean heart rate (min^{-1}) in groups I, II, and III

Stage	Group I Mean $\pm$ SD	Group II Mean $\pm$ SD	Group III Mean $\pm$ SD	F value	P value	Result
Immediately during insufflation	94.48 $\pm$ 11.57	98.44 $\pm$ 11.78	97.52 $\pm$ 17.20	0.566	0.570	N.S.
5 min after CO ₂ insufflation	95.20 $\pm$ 11.19	97.56 $\pm$ 11.45	101.20 $\pm$ 8.23	1.163	0.318	N.S.
10 min after CO ₂ insufflation	96.12 $\pm$ 11.25	97.36 $\pm$ 11.82	106.28 $\pm$ 14.82	4.737	0.011	SIG.
20 min after CO ₂ insufflation	96.45 $\pm$ 10.83	94.33 $\pm$ 12.54	105.25 $\pm$ 10.19	5.205	0.008	SIG
30 min after CO ₂ insufflation	97.50 $\pm$ 10.83	— ^a	112.40 $\pm$ 12.19	4.56 ^b	0.0001	HS
At exsufflation	92.16 $\pm$ 10.32	88.28 $\pm$ 13.23	104.52 $\pm$ 12.79	12.110	0.0001	HS
10 min after exsufflation	87.88 $\pm$ 10.97	86.56 $\pm$ 11.67	100.56 $\pm$ 12.14	11.080	0.0001	HS

^a In this group, only one patient's surgery continued till 30 min with a value-96

^b Unpaired Student's *t* test (two tailed) used to assess difference. (F=ANOVA)

Group I Intra-abdominal pressure was maintained between 8 and 10 mmHg.
 Group II Intra-abdominal pressure was maintained between 11 and 13 mmHg.
 Group III Intra-abdominal pressure was maintained at 14 mmHg and above.

In the operation theatre after attaching monitors to the patient, the following base line parameters were monitored.

Heart rate
 Noninvasive blood pressure
 (Systolic and mean)
 End-tidal carbon dioxide

All the above-mentioned parameters were monitored at various intervals, that is,

Immediately during insufflation.
 5 min after CO₂ insufflation
 10 min after CO₂ insufflation
 20 min after CO₂ insufflation
 30 min after CO₂ insufflation
 After every 10 min if surgery exceeds 30 min
 At exsufflation
 10 min after CO₂ exsufflation

Patients were ventilated with Padius Drager Ventilator keeping tidal volume 8–10 ml/kg and respiratory rate 12–14 breaths/min.

During surgery, patients were placed in reverse Trendlenburg position (head up) at 15 ° and right side of table elevated in order to have gut loops away from the site of surgery.

The results obtained were evaluated statistically and analyzed.

Observations and Results

The mean heart rate increased immediately during insufflation, 5, 10, 20, and 30 min after insufflation and decreased at exsufflation and 10 min after exsufflation in all the three groups. The difference in the mean heart rate was statistically significant at 10 and 20 min after CO₂ insufflation, and highly significant at 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 1).

The mean systolic blood pressure increased immediately during insufflation, 5, 10, 20, and 30 min after insufflation and decreased at exsufflation and 10 min after exsufflation in all the three groups. The difference was statistically significant, immediately during insufflation and highly

Table 2 Mean systolic blood pressure (mmHg) in groups I, II, and III

Stage	Group I Mean $\pm$ SD	Group II Mean $\pm$ SD	Group III Mean $\pm$ SD	F value	P value	Result
Immediately during insufflation	124.12 $\pm$ 9.98	132.72 $\pm$ 6.68	128.12 $\pm$ 13.50	4.254	0.0179	SIG
5 min after CO ₂ insufflation	125.96 $\pm$ 9.48	134.92 $\pm$ 6.56	136.28 $\pm$ 10.27	9.872	0.0001	HS
10 min after CO ₂ insufflation	127.36 $\pm$ 9.42	135.76 $\pm$ 7.16	140.32 $\pm$ 8.89	14.784	0.0001	HS
20 min after CO ₂ insufflation	128.75 $\pm$ 9.78	140.88 $\pm$ 8.21	143.20 $\pm$ 8.12	15.557	0.0001	HS
30 min after CO ₂ insufflation	128.85 $\pm$ 7.50	— ^a	143.60 $\pm$ 7.79	6.63 ^b	0.0001	HS
At exsufflation	124.88 $\pm$ 9.37	136.72 $\pm$ 5.77	136.44 $\pm$ 7.12	19.896	0.0001	HS
10 min after exsufflation	123.00 $\pm$ 9.23	125.68 $\pm$ 7.61	133.56 $\pm$ 6.57	12.118	0.0001	HS

^a In this group, only one patient's surgery continued till 30 min with a value-130

^b Unpaired Student's *t* test (two tailed) used to assess difference. (F=ANOVA)

Table 3 Mean arterial pressure (mmHg) in groups I, II, and III

Stage	Group I Mean±SD	Group II Mean±SD	Group III Mean±SD	F value	P value	Result
Immediately during insufflation	95.08±6.77	101.00±5.08	99.96±8.66	5.101	0.0084	SIG
5 min after CO ₂ insufflation	96.56±6.86	102.80±5.72	104.80±7.79	9.848	0.0001	HS
10 min after CO ₂ insufflation	97.44±6.51	103.80±6.42	108.00±7.05	15.869	0.0001	HS
20 min after CO ₂ insufflation	98.75±6.18	105.88±5.13	110.60±6.31	20.265	0.0001	HS
30 min after CO ₂ insufflation	98.95±6.13	— ^a	113.20±4.43	9.88 ^b	0.0001	HS
At exsufflation	95.36±5.98	104.48±4.96	105.64±6.51	23.103	0.0001	HS
10 min after exsufflation	93.56±5.89	95.68±5.39	101.72±6.30	12.987	0.0001	HS

^a In this group, only one patient's surgery continued till 30 min with a value-105

^b Unpaired Student's *t* test(two tailed) used to assess difference. (F=ANOVA)

significant at 5, 10, 20 and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 2).

The mean arterial pressure increased during insufflation, 5, 10, 20, and 30 min after insufflation and decreased at exsufflation and 10 min after exsufflation in all the three groups. The difference was statistically significant immediately during insufflation and highly significant at 5, 10, 20, and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 3).

The end-tidal CO₂ increased immediately after insufflation and the rise in EtCO₂ continued with the increasing period of CO₂ insufflation and even at 10 min after exsufflation the mean values were higher than the base line in all the three groups. The difference was statistically highly significant at 5, 10, 20, and 30 min after CO₂ insufflation at exsufflation and 10 min after exsufflation (Table 4).

The intergroup comparison of mean heart rate was statistically highly significant at 10, 20, and 30 min after CO₂ insufflation, which continued at exsufflation and 10 min after CO₂ exsufflation, whereas comparison of mean systolic blood pressure was statistically highly significant at 5, 10, 20, and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 5).

The intergroup comparison of mean arterial pressure was statistically significant during insufflation and highly

significant at 5, 10, 20, and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation, whereas comparison of end-tidal CO₂ was statistically significant immediately after insufflation and highly significant at 5, 10, 20, and 30 min after insufflation, at exsufflation, and 10 min after exsufflation (Table 5).

The intergroup comparison of mean heart rate was statistically highly significant at 10 and 20 min after CO₂ insufflation, which continued at exsufflation and 10 min after CO₂ exsufflation, whereas comparison of mean systolic blood pressure was statistically significant at 10 min after exsufflation (Table 6).

The intergroup comparison of mean arterial pressure was statistically significant at 20 min after insufflation and changes were highly significant at 10 min after exsufflation, whereas comparison of end-tidal CO₂ was significant after insufflation and highly significant at 5, 10, 20, and 30 min after insufflation, at exsufflation, and 10 min after exsufflation (Table 6).

Discussion

Analysis of Heart Rate In all the three groups, the mean heart rate increased during CO₂ insufflation and the rise in the heart rate continued till exsufflation, after which it

Table 4 End-tidal CO₂ (mmHg) in groups I, II, and III

Stage	Group I Mean±SD	Group II Mean±SD	Group III Mean±SD	F value	P value	Result
Immediately during insufflation	31.96±2.74	32.28±3.02	34.68±3.30	6.014	0.003	SIG.
5 min after CO ₂ insufflation	32.92±2.76	33.12±2.92	37.92±2.78	25.114	0.0001	H.S.
10 min after CO ₂ insufflation	33.56±2.69	34.08±3.01	41.04±2.55	57.196	0.00	H.S.
20 min after CO ₂ insufflation	34.20±2.70	35.88±2.54	42.80±1.85	72.145	0.00	H.S.
30 min after CO ₂ insufflation	37.00±2.58	— ^a	43.80±1.09	12.13 ^b	0.0001	H.S.
At exsufflation	33.00±2.95	33.84±2.96	40.12±1.92	53.434	0.00	H.S.
10 min after exsufflation	32.04±2.92	32.20±3.16	37.52±2.12	31.647	0.0001	H.S.

^a In this group, only one patient's surgery continued till 30 min with a value-39.

^b Unpaired Student's *t* test(two tailed) used to assess difference. (F=ANOVA)

Table 5 Intergroup comparison (group I v/s III) of mean heart rate, systolic blood pressure, mean arterial pressure, and end-tidal CO₂

Stage	Mean heart rate	Systolic blood pressure	Mean arterial pressure	End-tidal CO ₂
Immediately during insufflation	–	0.538	0.048	0.006
5 min after CO ₂ insufflation	0.403	0.0003	0.0001	0.0001
10 min after CO ₂ insufflation	0.001	0.0001	0.0001	0.0001
20 min after CO ₂ insufflation	0.04	0.0001	0.0001	0.00
30 min after CO ₂ insufflation	0.0001	0.0001	0.0001	0.0001
At exsufflation	0.0007	0.0001	0.0001	0.0001
10 min after exsufflation	0.0007	0.0001	0.0001	0.0001

Bonferroni test

decreased and at 10 min after exsufflation, the heart rates were comparable with the baseline (Table 1).

This rise in heart rate can be attributed to decreased venous return, which in turn decreases the cardiac output with a compensatory increase in the heart rate and due to hypercarbia caused by CO₂ insufflation, which leads to sympathetic stimulation as a result of release of catecholamines [13, 14].

The intergroup comparison of mean heart rate between groups I and III was statistically significant at 10, 20, and 30 min after CO₂ insufflation, which continued at exsufflation and 10 min after CO₂ exsufflation (Table 5). The comparison between groups II and III showed statistically significant difference at 10 and 20 min after CO₂ insufflation, at exsufflation, and 10 min after CO₂ exsufflation (Table 6).

On intergroup comparison, difference in heart rate was statistically significant after CO₂ insufflation, that is, when the other two groups (groups I and II) were compared with the high CO₂ pressure group (group III). This significant increase in heart rate can be explained on the basis of increased sympathetic stimulation and more compromised venous return in group III patients because of high pressure of CO₂ used [12, 15].

Analysis of Systolic Blood Pressure In all the three groups, the mean systolic blood pressure increased during CO₂ insufflation, 5, 10, 20, and 30 min after CO₂ insufflation, but decreased at exsufflation and 10 min after CO₂ exsufflation (Table 2).

The increase in systolic blood pressure after CO₂ insufflation can be explained on the basis of the reflex increase in systemic vascular resistance in response to the abdominal distention, an increase in afterload to heart and as a result of sympathetic effects of CO₂ absorbed from peritoneal cavity [16–17]. After exsufflation the fall in systolic blood pressure is because of the reversal of effects of CO₂ pneumoperitoneum.

The intergroup comparison between groups II and III showed statistically significant difference at 10 min after exsufflation (Table 6). However, the intergroup comparison between groups I and III showed statistically significant difference at 5, 10, 20, and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 5). This significant difference after insufflation between the low pressure (group I) and high pressure (group III) group is explained by more abdominal distention in the latter, leading to significant increase in systemic vascular resistance and afterload to heart and as a result of sympathetic effects of CO₂ [12, 18, 19].

Analysis of Mean Arterial Pressure In all the three groups, the mean arterial pressure increased during CO₂ insufflation and the rise in mean arterial pressure continued with increasing period of pneumoperitoneum. There was a fall in mean arterial pressure at exsufflation and 10 min after exsufflation (Table 3).

The rise in mean arterial pressure with CO₂ insufflation is due to the rise in systemic vascular resistance, sympathetic effects of CO₂ absorbed from peritoneal cavity, and due to the release of humoral mediators as a result of increased

Table 6 Intergroup comparison (group II v/s III) of mean heart rate, systolic blood pressure, mean arterial pressure and end-tidal CO₂

Stage	Mean heart rate	Systolic blood pressure	Mean arterial pressure	End-tidal CO ₂
Immediately during insufflation	–	0.370	–	0.019
5 min after CO ₂ insufflation	–	–	0.915	0.0001
10 min after CO ₂ insufflation	0.001	0.190	0.087	0.0001
20 min after CO ₂ insufflation	0.01	–	0.052	0.0001
30 min after CO ₂ insufflation	–	–	–	–
At exsufflation	0.001	–	–	0.0001
10 min after exsufflation	0.001	0.002	0.001	0.0001

Bonferroni test

intra-abdominal pressure [13, 16]. After exsufflation, the fall in mean arterial pressure could be because of reversal of effects of CO₂ pneumoperitoneum.

The intergroup comparison between group II and group III showed significant difference at 20 min after CO₂ insufflation and at 10 min after exsufflation (Table 6). The intergroup comparison between groups I and III showed significant statistical difference during insufflation, 5, 10, 20, and 30 min after CO₂ insufflation, at exsufflation, and 10 min after exsufflation (Table 5) [15, 20].

Analysis of EtCO₂ In all the three groups the end-tidal CO₂ increased immediately after insufflation and the rise in EtCO₂ continued with the increasing period of CO₂ insufflation till exsufflation. At 10 min after exsufflation, the mean values were higher than the base line in all the three groups (Table 4).

Comparison between group I and group III (Table 5) and between group II and group III (Table 6) showed highly significant statistical difference in EtCO₂ immediately after insufflation and the same trend was seen till the completion of surgery and even 10 min after exsufflation.

These results point out to the fact that comparison of groups I and II with group III (high pressure group) showed significant difference at all stages of surgery after CO₂ insufflation [20, 21].

The rise in EtCO₂ after CO₂ insufflation is explained on the basis of absorption of CO₂ as a result of higher CO₂ tension gradient between the pneumoperitoneum and the blood perfusing the peritoneum. Higher values of EtCO₂ at the end of the surgery can be explained by the high pressure gradient and increased absorption of CO₂.

Conclusion

The following conclusions were drawn from the study.

- Laparoscopic cholecystectomy induces significant hemodynamic changes intraoperatively.
- The majority of pathophysiological changes are related to cardiovascular system and are caused by CO₂ insufflation.
- High intra-abdominal pressure due to CO₂ insufflation is associated with more fluctuations in hemodynamic parameters and increased peritoneal absorption of CO₂ as compared with low intra-abdominal pressure.
- Even in ASA grade I and II patients laparoscopic cholecystectomy causes significant hemodynamic changes. Although these physiological changes generally do not need any intervention, but it makes continuous intraoperative monitoring mandatory.
- Low-pressure pneumoperitoneum is ideal for laparoscopic cholecystectomy and minimizes the adverse hemodynamic effects of CO₂ insufflation.

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